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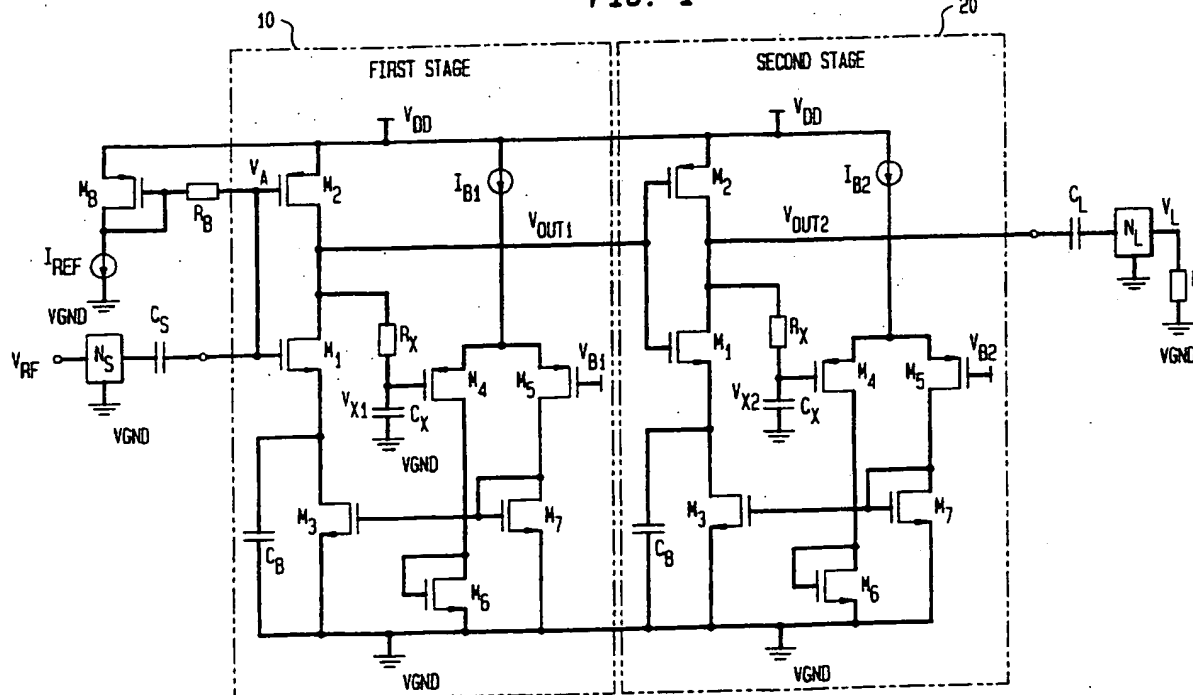
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(54) **An efficient RF CMOS amplifier with increased transconductance**

(57) An RF IC having an improved transconductance comprises a first active device ( $M_1$ ) of a first conductance type having a gate, a drain and a source, and a second active device ( $M_2$ ) of a second conductance type having a gate, a drain and a source. The second active device is coupled in series with the first active device. The gate of the first active device is coupled to the

gate of the second active device. A current reuse circuit ( $M_3$  to  $M_8$ ) is coupled to the first active device and the second active device wherein a current flowing from the drain of the first active device is reused in the second active device whereby transconductance is increased without an increased current utilization and without an increase in noise.

FIG. 1



a cascade connection of two transconductance amplifier stages. One advantage of the two-stage design is that reverse isolation of the LNA is improved in comparison to a single stage design. Another advantage is that by decoupling the input and output ports matching is simplified. An RF signal is applied at  $V_{RF}$ , which drives MOS gates  $M_1$  and  $M_2$  in the first stage. Since an external image rejection filter is typically used between the LNA output and the mixer RF input, the LNA output is capable of driving a load resistance  $R_L$  of 50  $\Omega$ .

As the first and second stage topologies are identical, only the operation of the first stage (single stage) is described herein. Again referring to FIG. 1, devices  $M_1$  and  $M_2$  are configured such that the transconductance of the stage is  $g_m = g_{m1} + g_{m2}$ , where  $g_{m1}$  is the transconductance of  $M_1$  and  $g_{m2}$  is the transconductance of  $M_2$ . Capacitor  $C_B$  shunts the source of  $M_1$  to ground at high frequencies. Since the drain current of  $M_1$  is reused in  $M_2$ ,  $g_m$  increases without increasing current consumption, in contrast to a common source amplifier composed of  $M_1$  or  $M_2$  alone. A bias feedback amplifier sets the dc output voltage  $V_{OUT1}$  of the stage to the bias reference  $V_{B1}$ . Devices  $M_3$ ,  $M_4$ ,  $M_5$ ,  $M_6$  and  $M_7$  steer bias current into devices  $M_1$  and  $M_2$ . The bias reference  $I_{REF}$  and the current mirror which is composed of devices  $M_8$  and  $M_2$  establish the desired bias current in devices  $M_1$  and  $M_2$ . The bias feedback loop is completed with a low pass filter comprised of  $R_X$  and  $C_X$ . The low pass filter provides dc output voltage  $V_{X1}$  from  $V_{OUT1}$ . The low frequency pole that is contributed by the filter dominates the bias feedback amplifier loop transmission to achieve a high phase margin for the loop. Direct coupling is utilized between the output of the first stage and the input of the second stage. The bias reference  $V_{B1}$  sets the dc output voltage  $V_{OUT1}$  for the first stage and thus sets the dc input voltage of the second stage, determining the second stage bias current. The second stage bias feedback amplifier sets the dc output voltage  $V_{OUT2}$  to bias reference  $V_{B2}$ . Where  $V_A$  is the dc input voltage of the first stage determined by  $I_{REF} V_{B1} = V_{B2} = V_A$ . Resistors  $R_B$  and  $R_X$  are chosen sufficiently large to prevent significant input and output loading.

Referring to FIG. 2 there is shown a schematic of a mixer according to the present invention. The mixer 30 comprises of 4 nMOS devices  $M_{13}$ ,  $M_{14}$ ,  $M_{19}$ , and  $M_{20}$ , 5 pMOS devices  $M_{11}$ ,  $M_{12}$ ,  $M_{15}$ ,  $M_{17}$ , and  $M_{21}$ , resistors  $R_{X1}$ ,  $R_{X2}$ ,  $R_{B1}$  and  $R_{B2}$  capacitor  $C_X$ , and current sources  $I_B$  and  $I_{REF}$ . The gate of  $M_{11}$  is coupled to the gate of  $M_{14}$  and  $V_{LO1}$ . The gate of  $M_{13}$  is coupled to the gate of  $M_2$  and  $V_{LO2}$ . The source of  $M_{16}$ , the source of  $M_{18}$ , and current source  $I_B$  are coupled to a supply voltage  $V_{DD}$ . The gate of  $M_{16}$  is coupled to  $V_{REF1}$ . The gate of  $M_{18}$  is coupled to the drain of  $M_{18}$ . Current source  $I_{REF}$  is coupled between the drain of  $M_{18}$  and supply voltage  $V_{GND}$ . Resistor  $R_{B1}$  is coupled between the gate of  $M_{16}$  and the gate of  $M_{18}$ . The drain of  $M_{16}$  is coupled between the source of  $M_{13}$  and the source of  $M_{14}$ . The drain of  $M_{13}$  is coupled to the drain of  $M_{11}$ . The drain of  $M_{14}$  is

coupled to the drain of  $M_{12}$ . The source of  $M_{11}$  and the source of  $M_{12}$  are coupled to the drain of  $M_{15}$ . The drain of  $M_{15}$  is coupled to  $V_{GND}$ .  $R_{X1}$  is coupled between the drain of  $M_{14}$  and the gate of  $M_{19}$ . The voltage at the gate of  $M_{19}$  is called  $V_X$ .  $R_{X2}$  is coupled between the drain of  $M_{11}$  and the gate of  $M_{19}$ .  $C_X$  is coupled between the gate of  $M_{19}$  and  $V_{GND}$ . The drain of  $M_{11}$  is coupled to  $V_{OUT2}$ . The drain of  $M_{14}$  is coupled to  $V_{OUT1}$ . The current source is coupled to the source of  $M_{19}$  and the source of  $M_{20}$ . The drain of  $M_{19}$  is coupled to the drain of  $M_{21}$  and the gate of  $M_{21}$ . The drain of  $M_{20}$  is coupled to the drain of  $M_{17}$  and the gate of  $M_{17}$ .  $R_{B2}$  is coupled between the gate of  $M_{15}$  and the gate of  $M_{17}$ . The source of  $M_{17}$ , the source of  $M_{21}$ , and the source of  $M_{15}$  are coupled to  $V_{GND}$ .

External networks  $N_S$  matches the mixer  $R_F$  port to 50 $\Omega$ . The RF input is applied at  $V_{RF}$ , driving  $V_{RF1}$  and  $V_{RF2}$ , and in turn gates  $M_{15}$  and  $M_{16}$ , in phase. Again referring to FIG. 2, devices  $M_{15}$  and  $M_{16}$  are configured as a transconductance amplifier where  $g_m = g_{m15} + g_{m16}$ , where  $g_{m15}$  is the transconductance of  $M_{15}$  and  $g_{m16}$  is the transconductance of  $M_{16}$ . The mixer amplifier uses the design principle used for the LNA stages such that  $g_m$  is increased while the drain current is reused, thus avoiding increased current consumption for increased  $g_m$ . The cross coupled devices  $M_{11}$ ,  $M_{12}$ ,  $M_{13}$  and  $M_{14}$  comprise the main mixer cell which is driven by the differential local oscillator (LO) inputs  $V_{LO1}$  and  $V_{LO2}$ . The drain currents of devices  $M_{15}$  and  $M_{16}$  are steered through devices  $M_{11}$  and  $M_{13}$  or through devices  $M_{12}$  and  $M_{14}$ , as a function of the LO phase. When an input  $V_{RF}$  is applied, the drain currents of  $M_{15}$  and  $M_{16}$  differ by  $g_m V_{RF}$ . This difference current is then chopped by the mixer cell resulting in the desired IF current at the output ports  $V_{OUT1}$  and  $V_{OUT2}$  of the mixer. The high impedance mixer outputs are capable of driving an external high impedance IF filter.

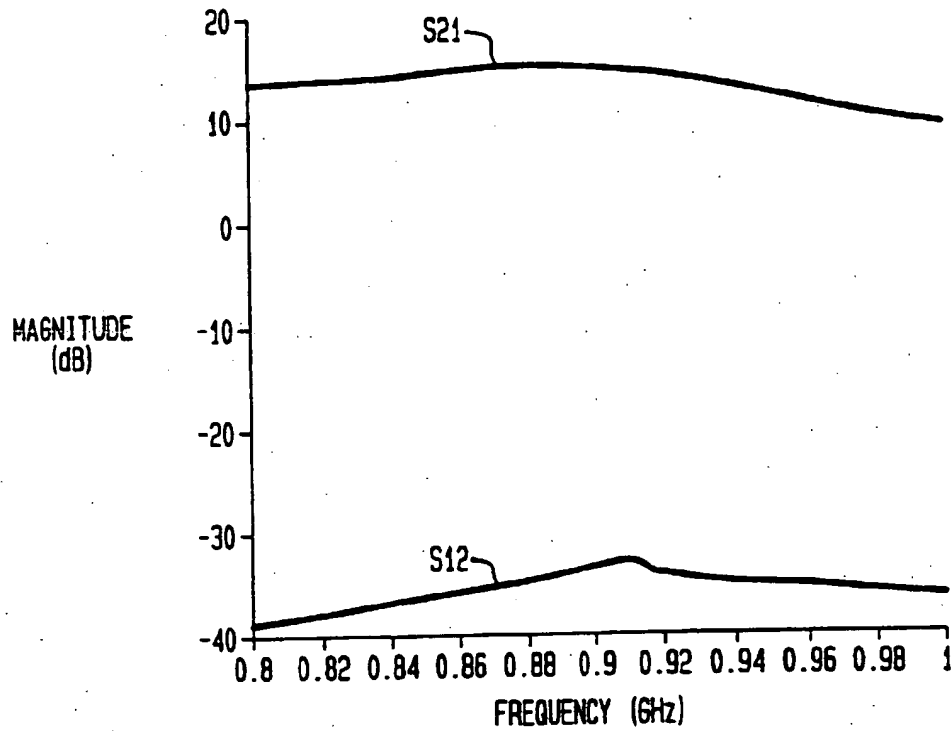
Biasing of the mixer is similar to that used for the LNA stages. A common mode feedback amplifier sets the dc common mode output level of the mixer,  $V_X$ , to the bias reference,  $V_B$ . A differential pair and current mirror are comprised of MOS devices  $M_{15}$ ,  $M_{17}$ ,  $M_{19}$ ,  $M_{20}$ , and  $M_{21}$ , which steer the bias current into the mixer cell. Bias reference  $I_{REF}$  and a current mirror comprised of MOS devices  $M_8$  and  $M_{16}$  establish the desired bias current in the mixer cell. A low pass filter completes the feedback loop. The low pass filter is comprised of  $R_{X1}$ ,  $R_{X2}$  and  $C_X$ . This provides the dc common mode level  $V_X$  from outputs  $V_{OUT1}$  and  $V_{OUT2}$ . Resistors  $R_{B1}$ ,  $R_{B2}$ ,  $R_{X1}$  and  $R_{X2}$  are selected sufficiently large to prevent significant input and output loading.

Referring to FIG. 3 there is shown a graph of the measured LNA forward and reverse gain magnitudes,  $|S_{21}|$  and  $|S_{12}|$ , respectively.

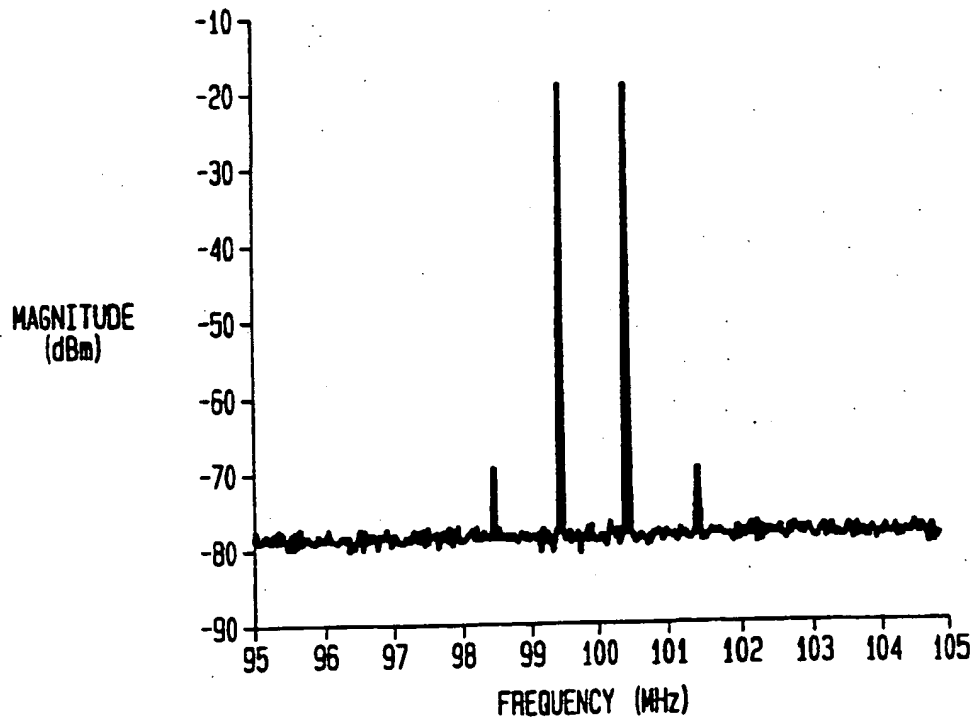
Referring to FIG. 4 there is shown a graph of the measured mixer IF output spectrum when a two tone RF input at 899.5 Mhz and 900.5 Mhz is mixed with a LO frequency at 1 Ghz. The RF power level is 29 dBm for



**FIG. 3**



**FIG. 4**





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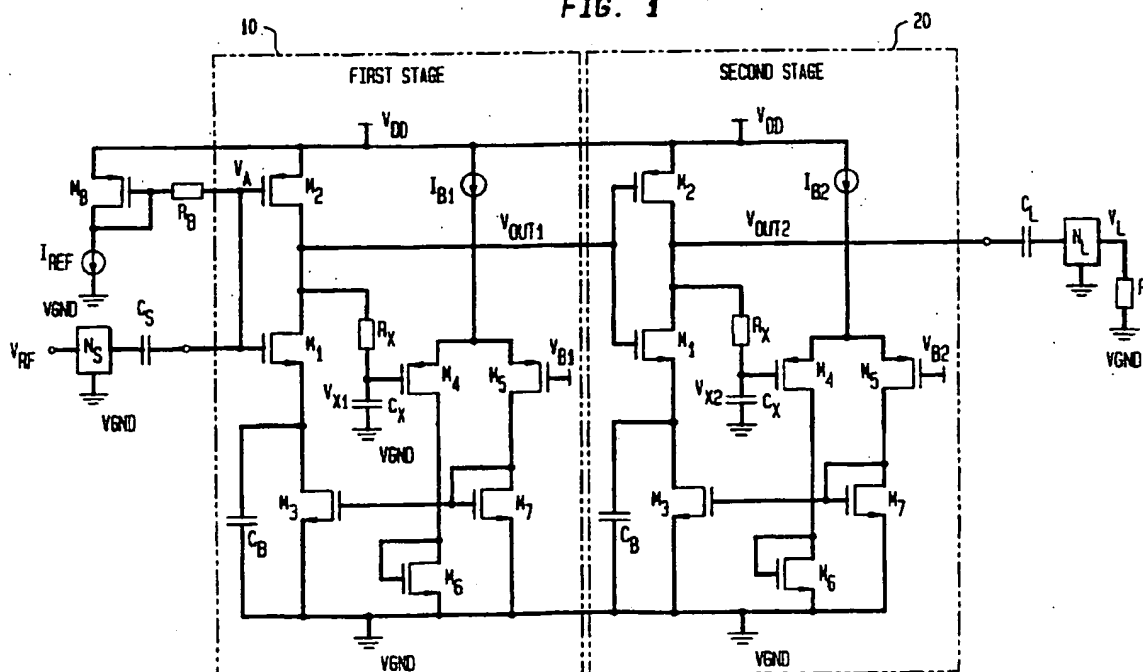
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**FIG. 1**



**ANNEX TO THE EUROPEAN SEARCH REPORT  
ON EUROPEAN PATENT APPLICATION NO.**

EP 97 30 0525

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.  
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